Internet Ops Concepts for Future Space Missions

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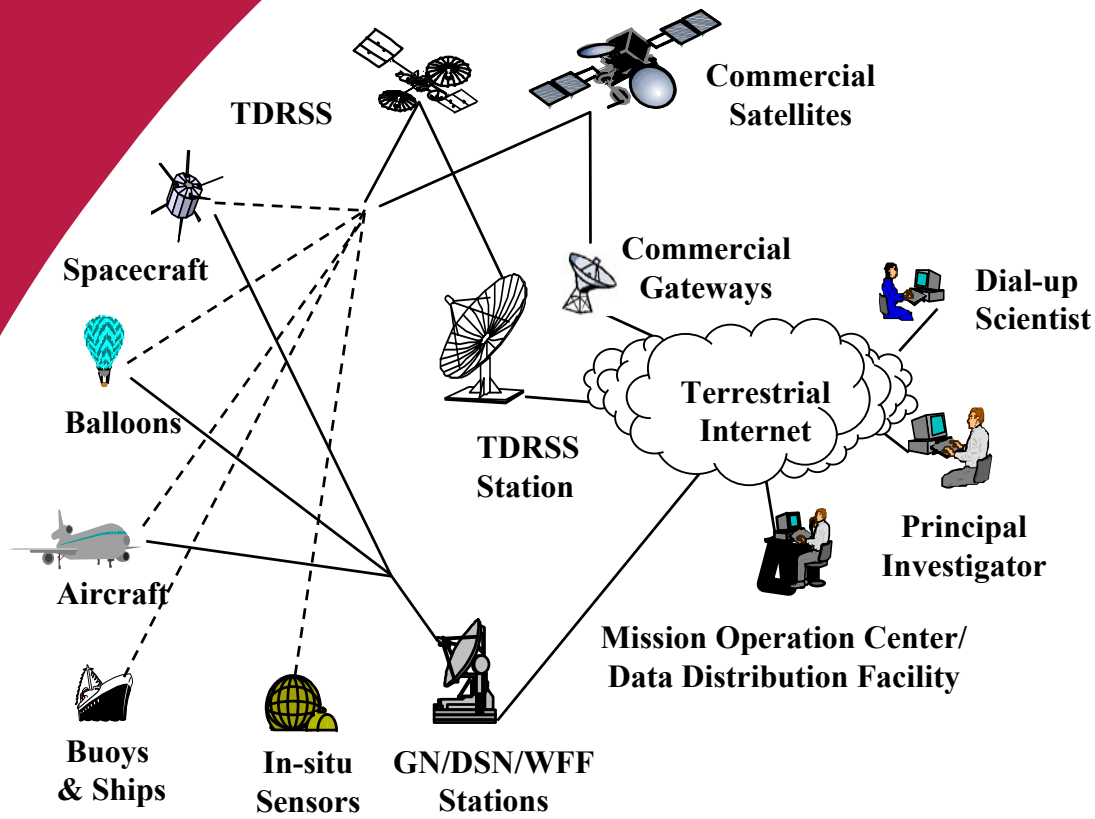


Overview

- Concepts
- Legacy Systems
- Internet Architecture for Space
- Data Flows and Protocols
- Future Efforts

Concepts

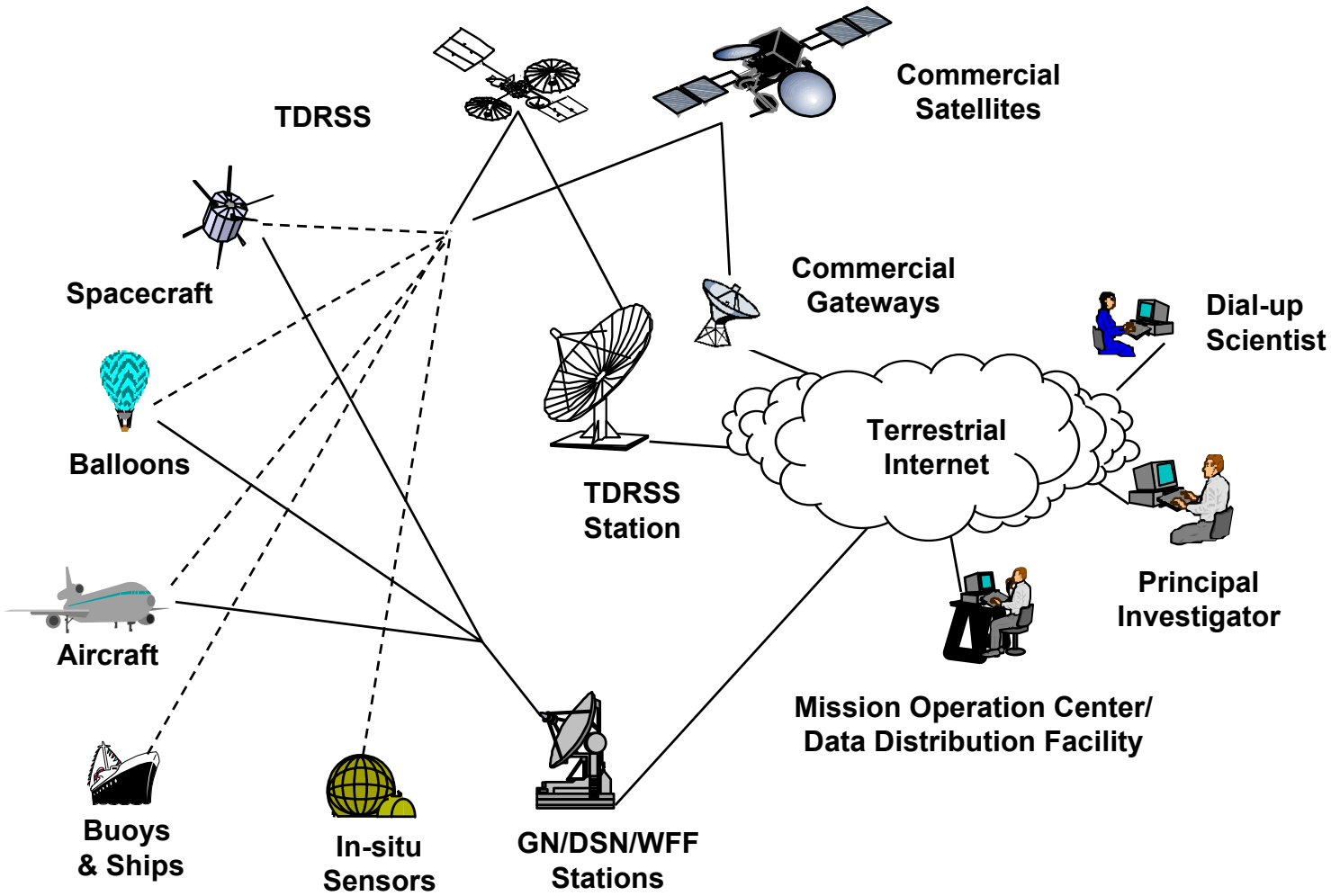
- Simple, cost-effective delivery of science data where and when needed
- Large-scale addressability and network connectivity among spacecraft and other science systems
- Design built on standard Internet protocols and distributed computing technologies
- Extensive use of commercial network technology

Concepts

- Same interface and control software used for instrument development, I&T, and operations
- Simpler and earlier integration & test across the Internet to find problems early in development
- Automated data delivery
- Reliable file delivery for higher quality data sets
- Timely data delivery
- Reduced operations staffing
- Operating Missions as Nodes on the Internet (OMNI) project at NASA/GSFC designing and demonstrating Internet based space communications solutions

http://ipinspace.gsfc.nasa.gov/

Science Network Communications

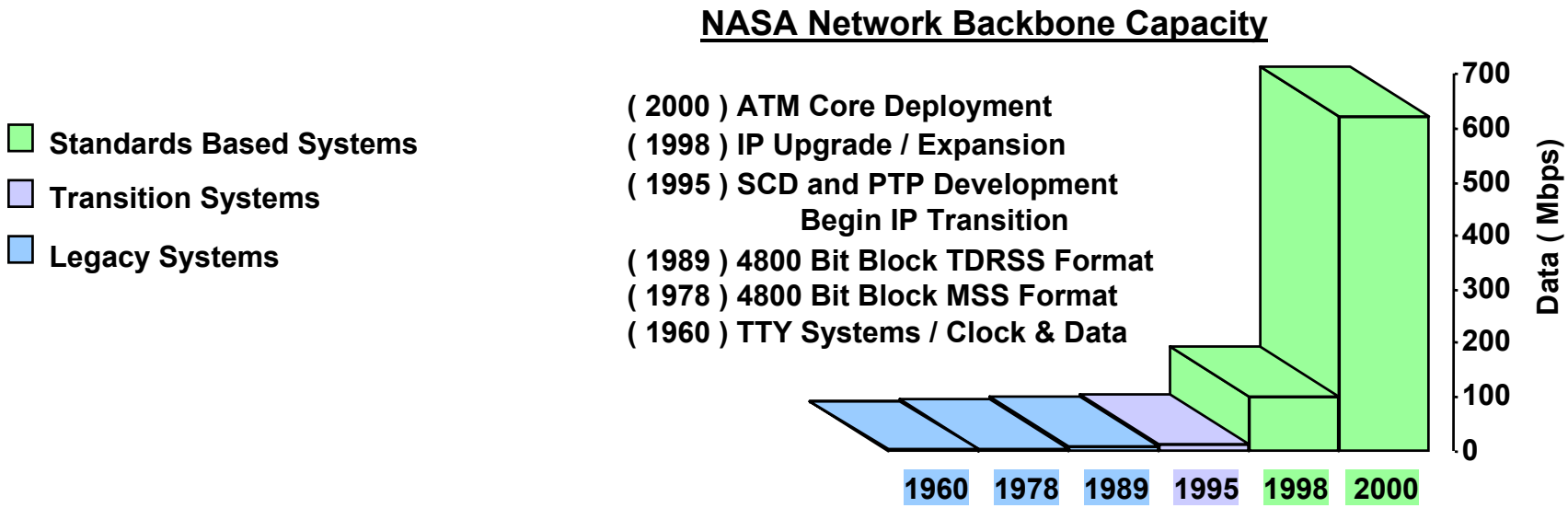


Legacy Systems

- Years ago NASA developed state-of-the-art communication technology since it didn't exist
- Result was a collection of custom systems with primarily point-to-point connectivity
- Large amount of scheduling, human intervention, and management required
- Spacecraft integration & test and mission operations required complicated test environments and custom equipment
- In the mid-1990s Nascom began migrating to more standard Internet technology

Legacy Network Upgrade

- Installed Internet Protocol (IP) backbone with standard routers
- Reduced number of different types of systems
- Reduced development, maintenance, and operations staffs
- Provided easy bandwidth upgrade options



Legacy Spacecraft Operations

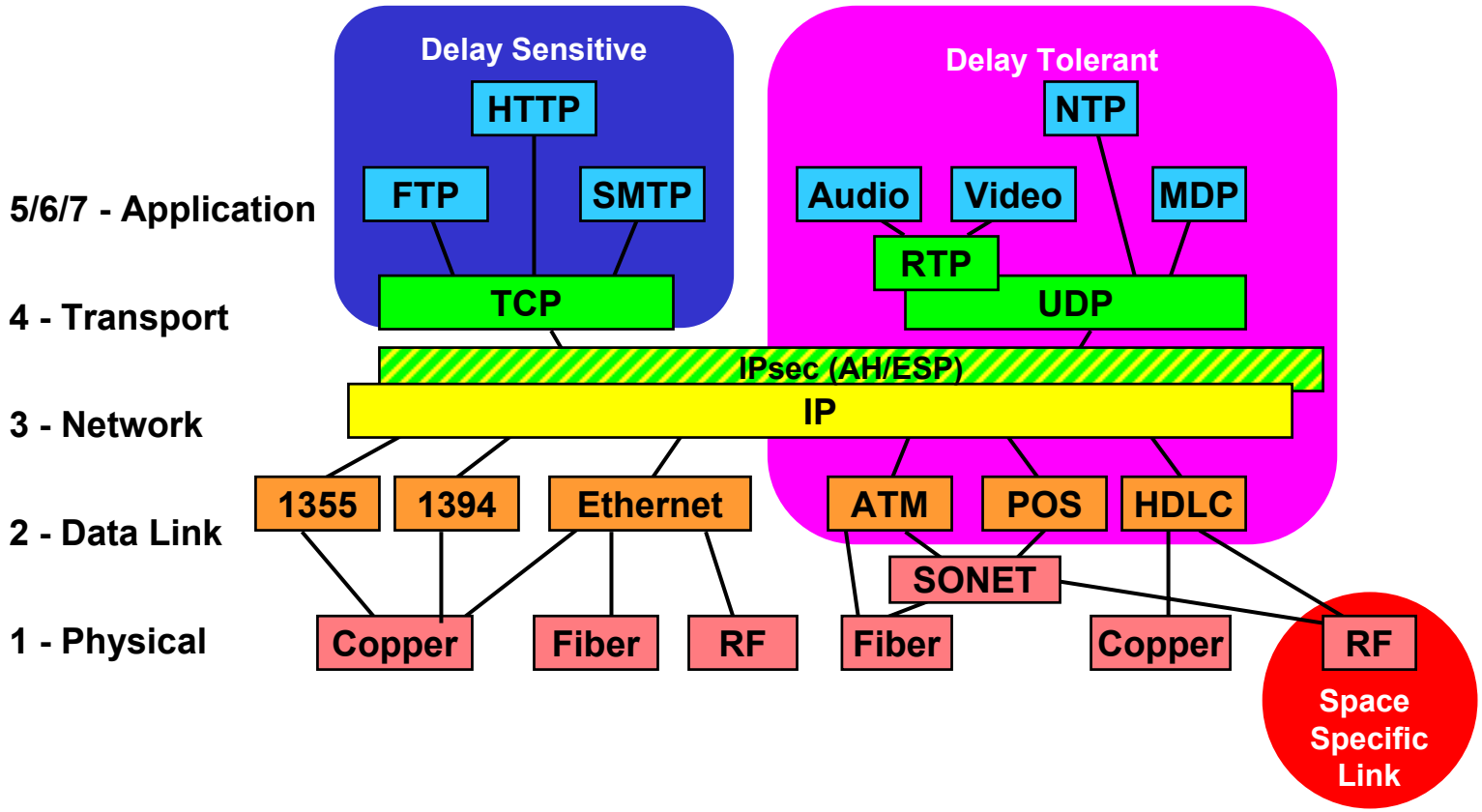
- Telemetry comes down from spacecraft
- Commands go up to spacecraft command & data handling (C&DH) system
- Telemetry and command data formats different
- Flight operations team (FOT) heavily involved in managing onboard storage system
- Reliable command delivery using acknowledged protocols (e.g. COP-1)
- Individual spacecraft only communicate with their Mission Operation Center (MOC) and custom ground systems, no crosslinks with other spacecraft

Internet Architecture for Space

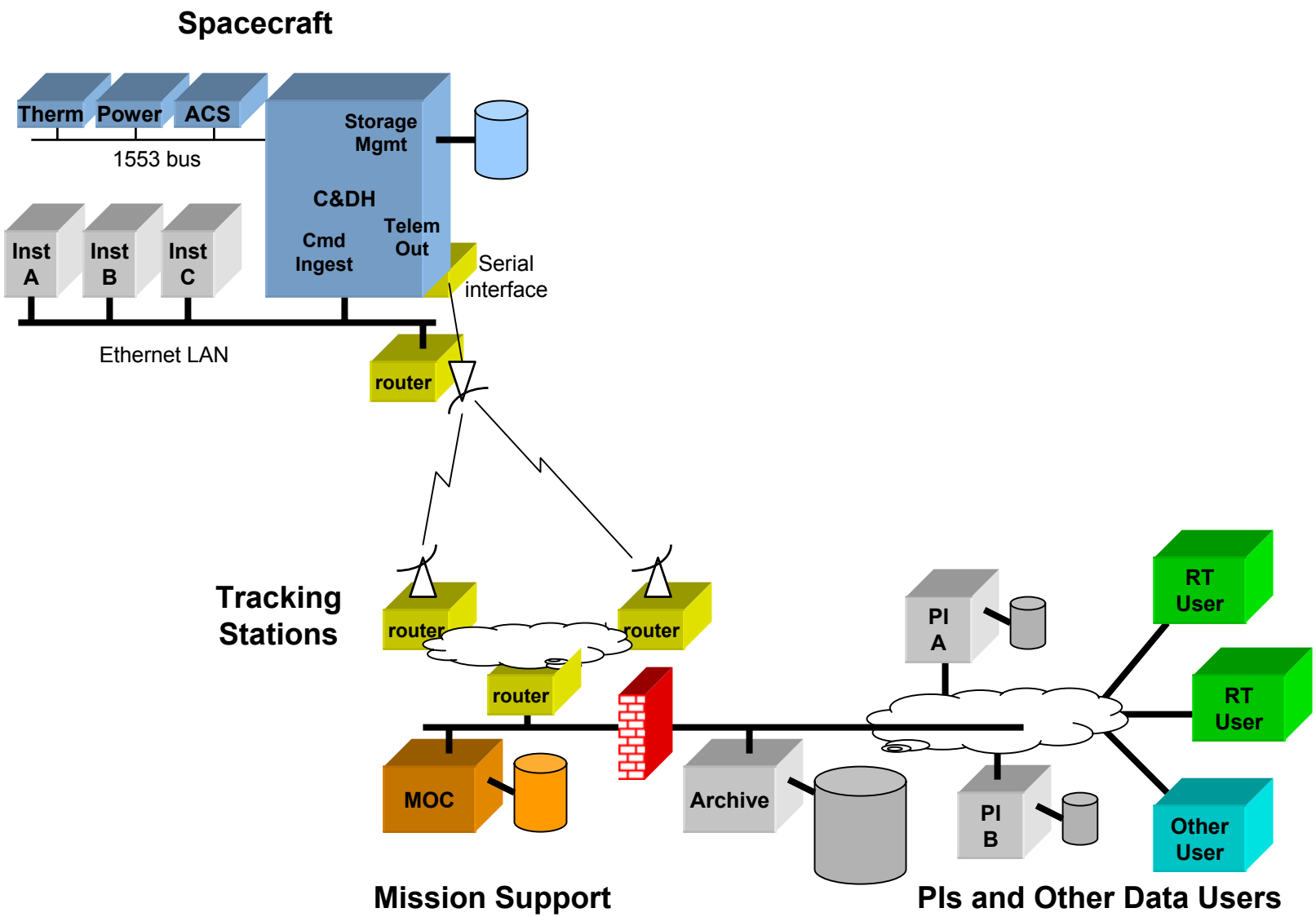
- Local Area Network (LAN) technology onboard
- Mass storage with random access file systems
- Operating systems with IP network support
- Standard applications use UDP and TCP APIs to communicate between instruments, onboard systems, and ground systems and possibly end users
- Frame Relay/HDLC frames over space link
- RF signal processed at ground and Frame Relay/HDLC bitstream fed to router serial ports
- Ground IP packets delivered over closed networks or properly secured open Internet links

Internet Protocols for Space

- Select proper Internet protocols for space use
- Follow protocol layering for flexibility

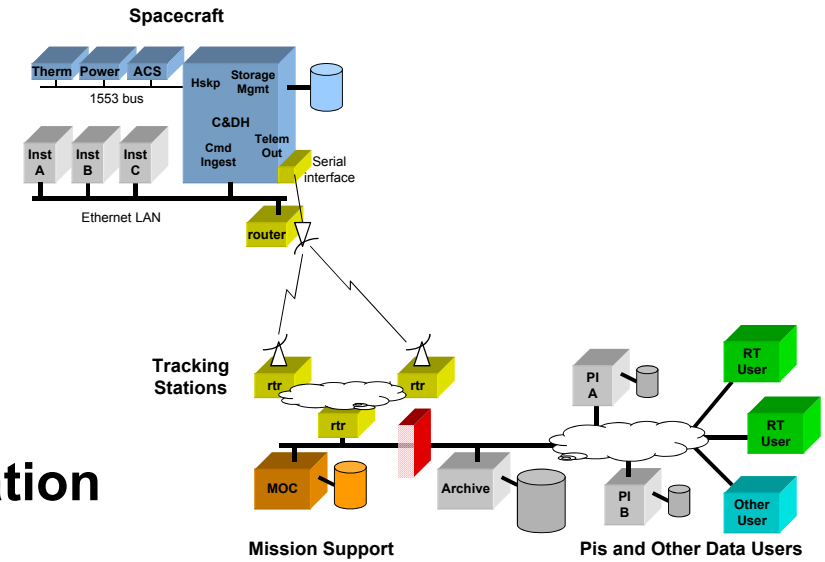


Instruments to End Users

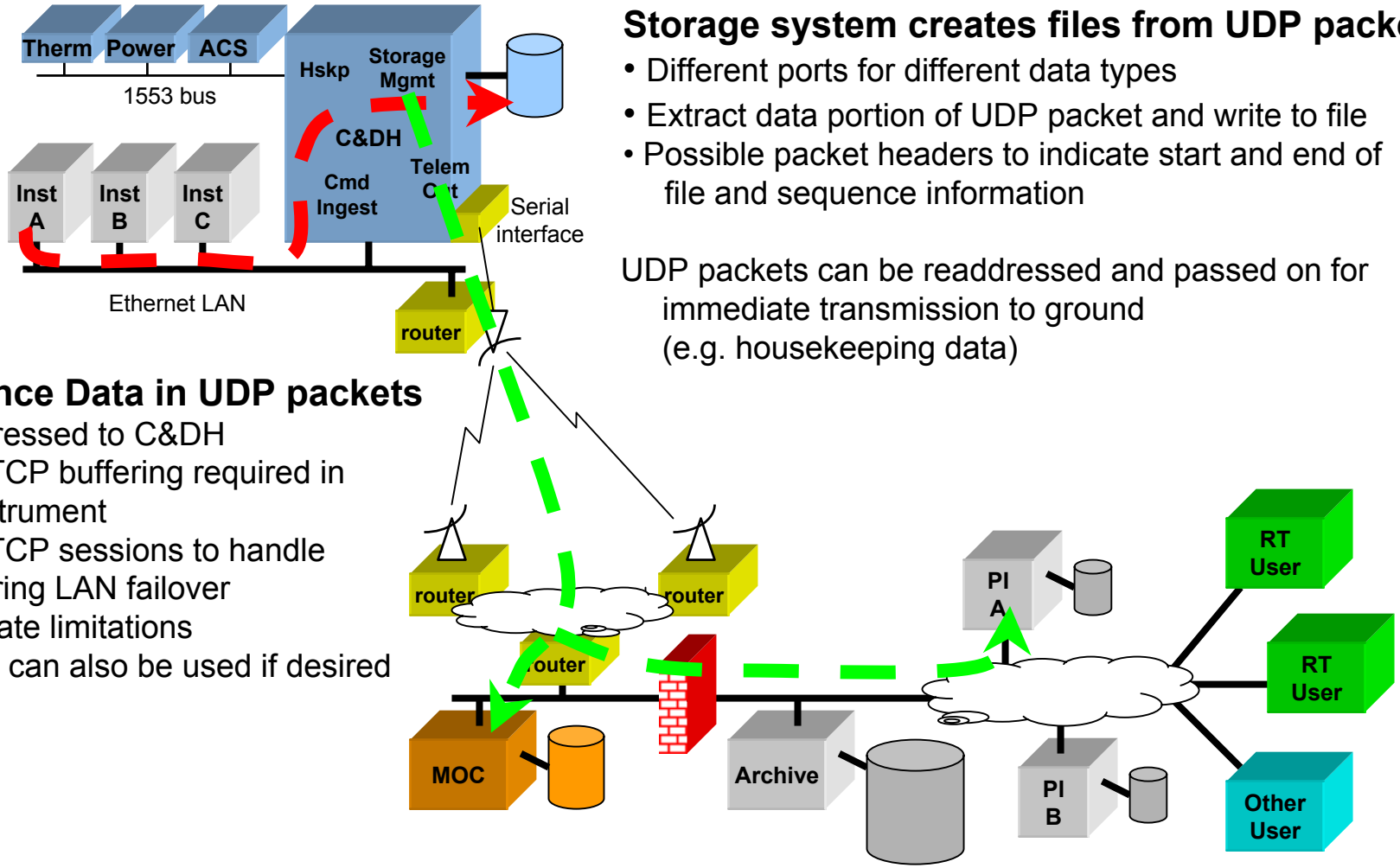


Data Flows and Protocols

- **Instrument to C&DH**
  - Stored data
  - Realtime data relay to ground
- **Onboard storage to ground (telemetry)**
  - Realtime delivery to one or more users
  - Store-and-forward delivery to one or more users
- **MOC to C&DH (commanding)**
  - Blind commanding
  - Single commands
  - Interactive command session
  - Stored command file upload
- **Instrument commanding**
  - From C&DH
  - Direct from ground
- **Spacecraft initiated communication**
  - Clock synchronization
  - Communication with other spacecraft



Instruments to C&DH



Storage system creates files from UDP packets

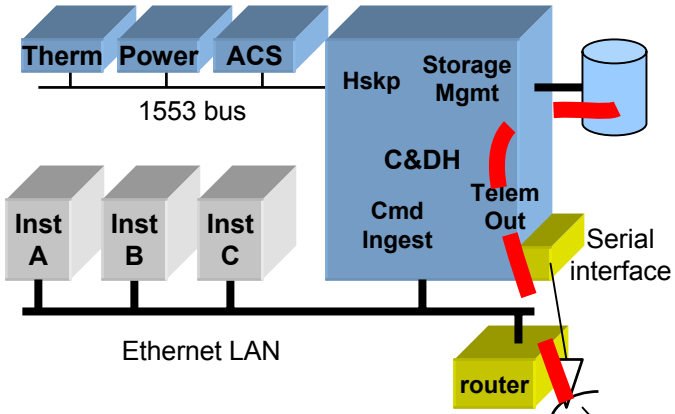
- Different ports for different data types
- Extract data portion of UDP packet and write to file
- Possible packet headers to indicate start and end of file and sequence information

UDP packets can be readdressed and passed on for immediate transmission to ground (e.g. housekeeping data)

Science Data in UDP packets

- Addressed to C&DH
- No TCP buffering required in instrument
- No TCP sessions to handle during LAN failover
- No rate limitations
- TCP can also be used if desired

Onboard Storage to Ground



Reliable transfer to few locations with best-effort file transfer to multiple destinations

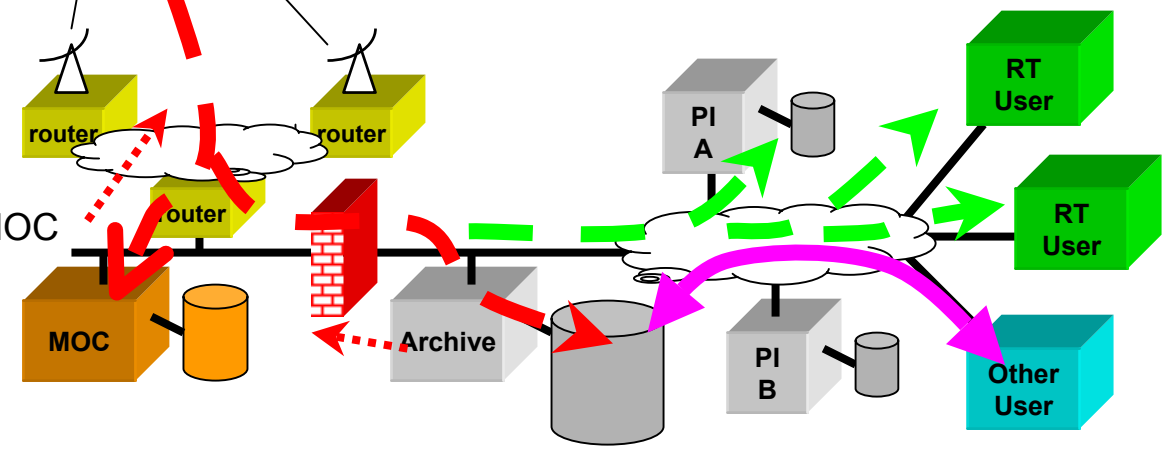
- MDP file transfer over one-way or two-way link using UDP multicast packets
- Reliable sites participate in MDP NACKs & final ACKs
- Best-effort sites take what they get and that's it
- Number of best-effort sites is unlimited
- Only one packet sent from spacecraft, ground replicates

Later reliable transfer to additional sites

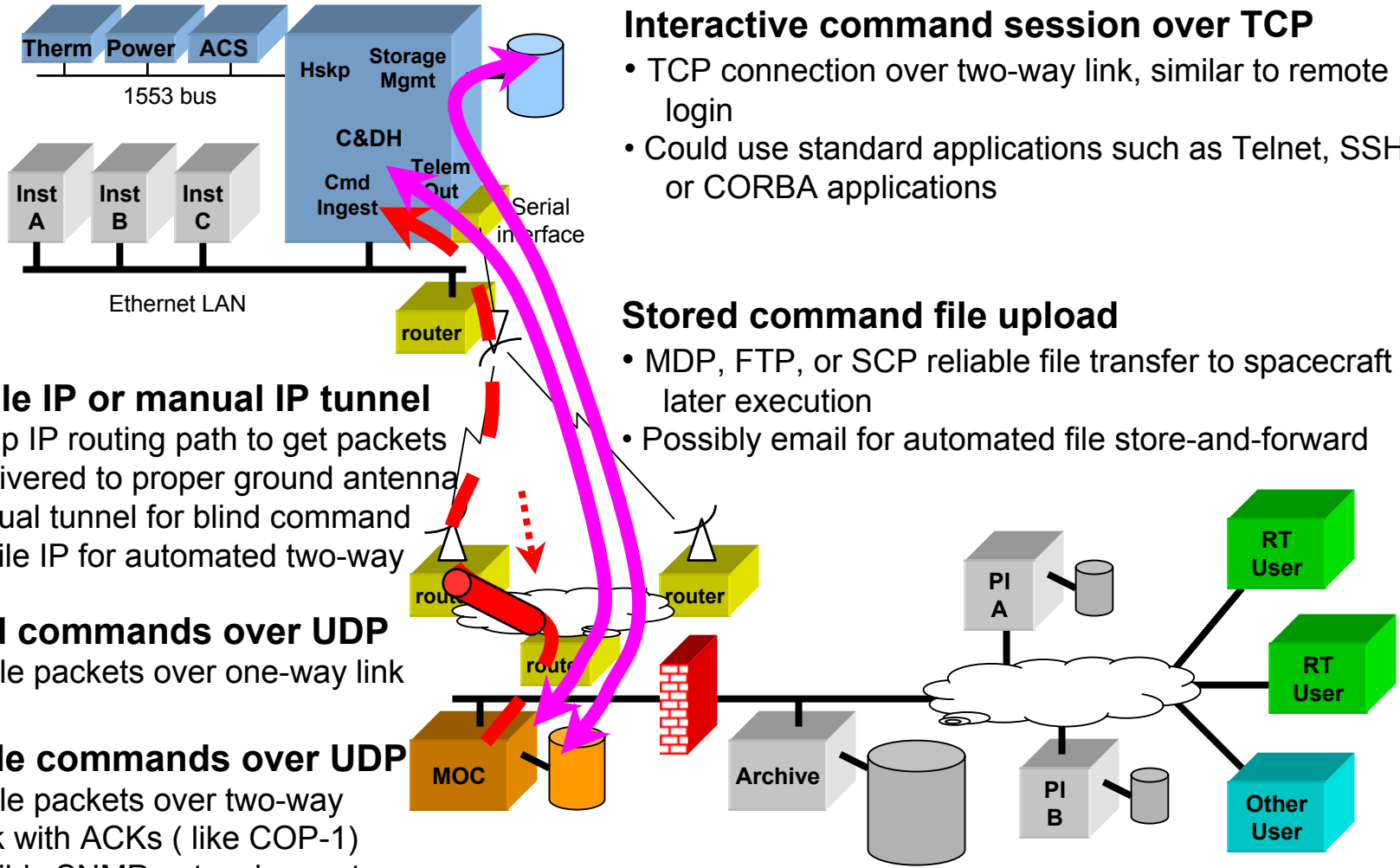
- MDP/UDP "push" to multiple sites
- FTP/TCP "push" or "pull" from individual sites

Reliable file transfer to MOC (unicast UDP packets)

- MDP file transfer over one-way link with later NACKs
- MDP file transfer over two-way link with NACKs
- Final file complete ACK from MOC
- FTP file transfer if appropriate



MOC to C&DH (commanding)



Interactive command session over TCP

- TCP connection over two-way link, similar to remote login
- Could use standard applications such as Telnet, SSH, or CORBA applications

Stored command file upload

- MDP, FTP, or SCP reliable file transfer to spacecraft for later execution
- Possibly email for automated file store-and-forward

Mobile IP or manual IP tunnel

- Setup IP routing path to get packets delivered to proper ground antenna
- Manual tunnel for blind command
- Mobile IP for automated two-way

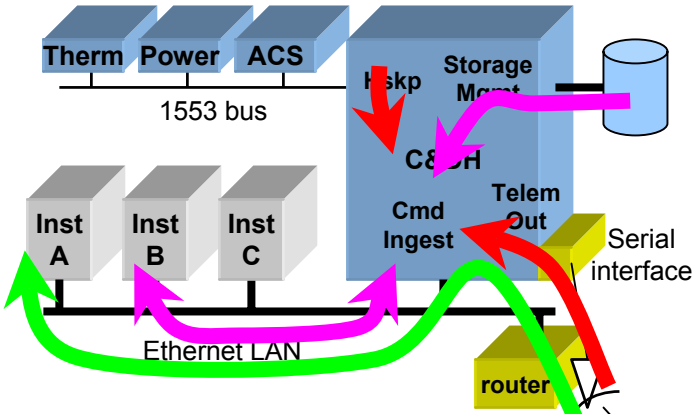
Blind commands over UDP

- Single packets over one-way link

Single commands over UDP

- Single packets over two-way link with ACKs (like COP-1)
- Possibly SNMP network mgmt

Instrument Commanding



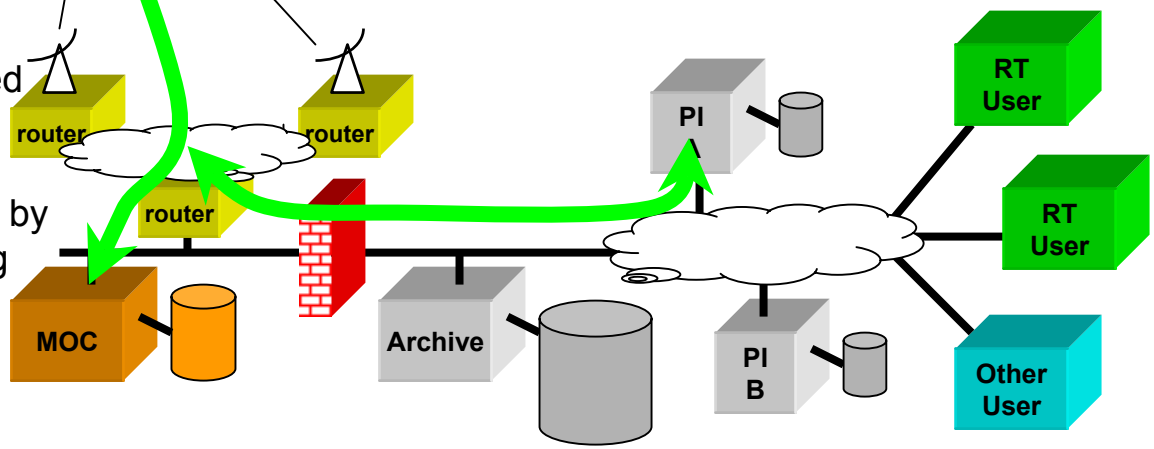
C&DH commands to instruments

- Commands originate from multiple sources
  MOC, stored command file, onboard automation
- C&DH uses a reliable TCP connection to guarantee command data transfer with instruments

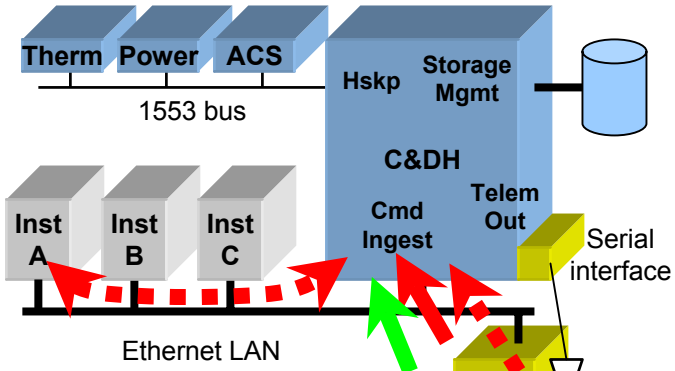
Commands direct from ground to the instrument

- Commands from multiple sources
  MOC, PI, other spacecraft
- Security issues must be addressed
- UDP or TCP could be used

- Packets forwarded to instruments by onboard router or C&DH routing
- Reduces workload on C&DH



Spacecraft Initiated Comm

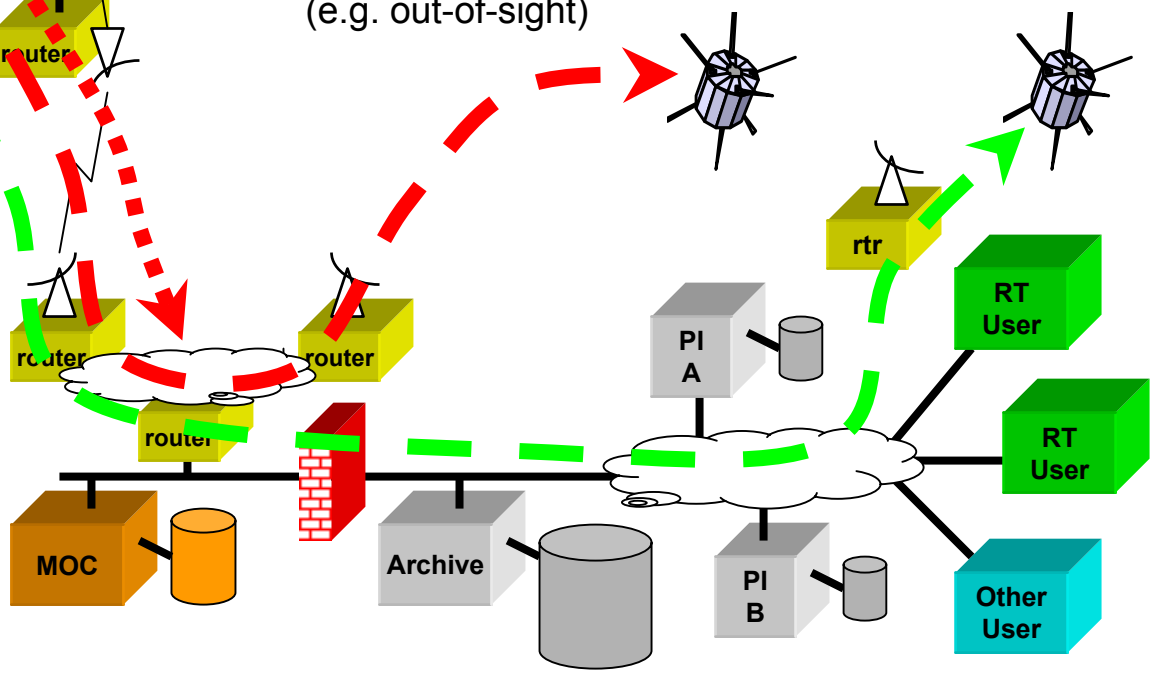


Communication with other spacecraft or sensors

- IP network layer hides lower layer communication details
- The address a packet is sent to could be onboard, on the ground, or another spacecraft
- This provides an alternative to crosslinks and can operate when crosslinks would not be available (e.g. out-of-sight)

Spacecraft clock sync

- Network Time Protocol (NTP) operates over UDP
- Provides high resolution time sync across an IP network
- Provides onboard and space-to-ground time synchronization
- NTP time servers already available on Closed IONET
- Ground systems use same protocol to set their clocks



Final Mission Design Choices

- **Everyone uses IP network layer to allow universal addressability and to hide lower layer details**
- **Space link uses Frame Relay/HDLC framing for easy interface to commercial ground network equipment**
- **Missions select applications over UDP or TCP based on their requirements**
  - Data rates
  - Link characteristics (e.g. one-way, two-way)
  - Type of data being transferred (e.g. housekeeping, science)
  - Big files versus small files
  - Mission data delivery requirements (e.g completeness, timeliness)
- **Security built on commercial solutions**
  - Tailored to meet mission security threats and needs
  - Must protect all associated networks from harm by this mission

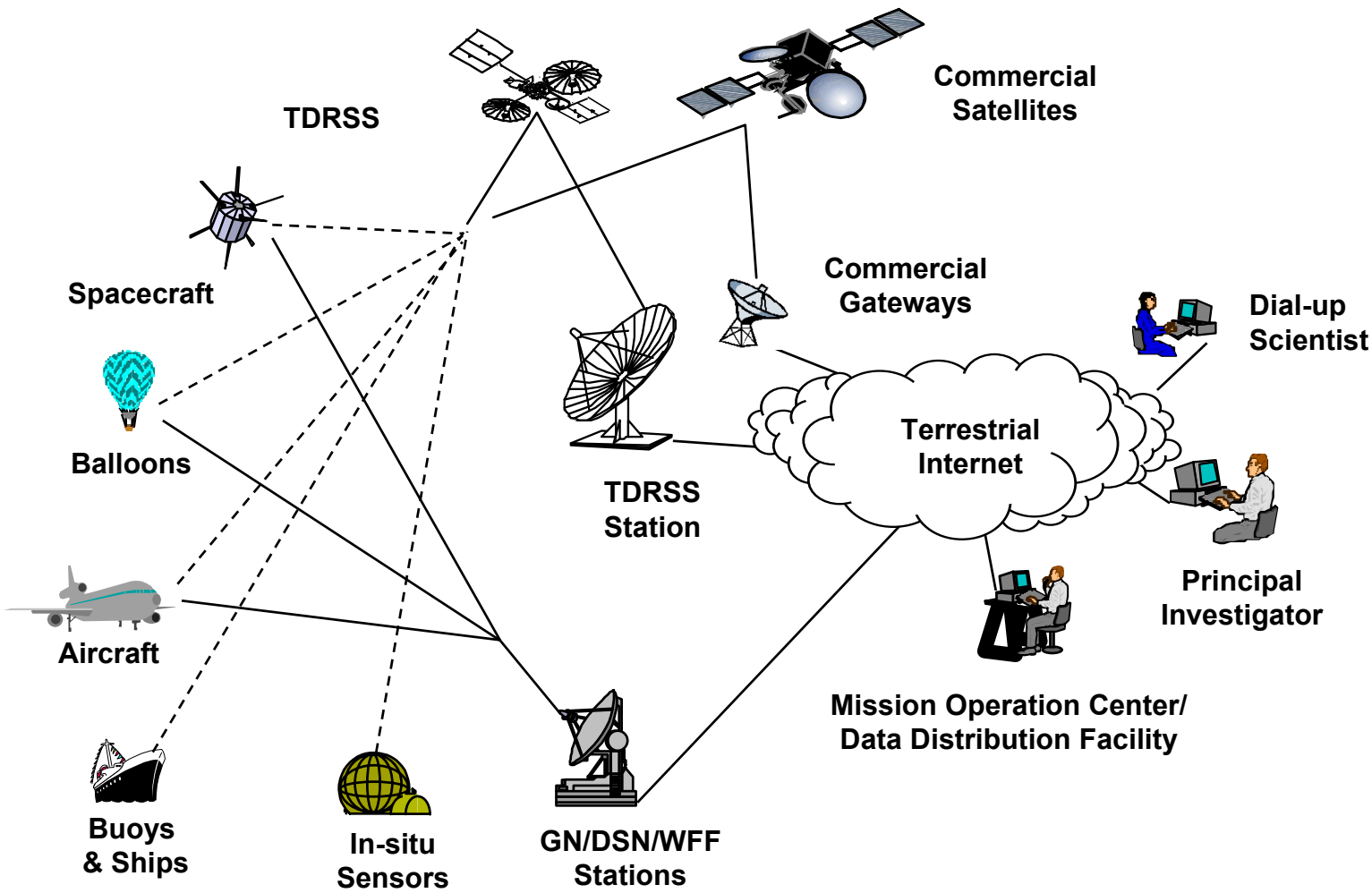
Flight Proven Concepts

- **UoSat-12 : Apr 2000 - Jan 2001**
  - Successful on-orbit demonstration of standard IP technology
  - HDLC, IP, FTP, NTP, HTTP, UDP Telemetry, UDP Commanding
- **AlSat-1 : Nov 2002**
  - First spacecraft to use IP for routine on-orbit operations
  - First of the 5-spacecraft Disaster Monitoring Constellation (DMS)
  - HDLC, IP, CFDP, UDP Telemetry, UDP Commanding
- **CHIPS : Dec 2002**
  - Second spacecraft to use IP for routine on-orbit operations
  - HDLC, IP, FTP, UDP Telemetry, UDP Commanding
- **CANDOS/STS-107 : Jan 2003**
  - Communication and Navigation Demo On Shuttle (CANDOS)
  - First mission on NASA's closed IONET to use IP for all operations
  - First on-orbit use of standard IP encryption technology
  - First on-orbit use of mobile-IP to multiple groundstations
  - HDLC, IP, Mobile IP, UDP telemetry, UDP commanding, NTP, MDP, SCP, SSH, telnet

Future Activities

- **IP Handbook**
  - A system engineer's guide to IP mission design
  - Work in progress, scheduled completion 3Q 2003
- **Network Mechanisms for S/C Clock Maintenance**
  - Detailed characterization of NTP for spacecraft clock sync
- **Security solutions for future operations**
  - Working with NASA/GSFC Security Organization on future security solutions based on emerging Internet security protocols
- **Magnetosphere MultiScale (MMS) mission**
  - Developing an end-to-end demo of IP based data delivery
- **Disaster Monitoring Constellation (DMS)**
  - 3 more IP spacecraft launching in 2003
- **Global Precipitation Measurement (GPM) mission**
  - Mission has selected the use of end-to-end IP
  - Design activities in progress
  - Projected launch 2007-2008

Future Science Communications



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